6-30-1917

Measuring Silage and Capacity of Silos

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AGRICULTURAL EXPERIMENT STATION

LINCOLN, NEBRASKA, JUNE 30, 1917

CIRCULAR NO. 1

MEASURING SILAGE AND CAPACITY OF SILOS

By L. W. CHASE, *Professor of Agricultural Engineering*

INTRODUCTION

The condition of the corn at filling time, the rate of filling, and the length of time settling has taken place before measuring the depth of the silage, all tend to cause variations in the weight per cubic foot of the silage and in the tonnage that can be placed in a silo. The greatest variation comes when very green corn or very ripe corn is used, and because of this it is possible that a cubic foot of green silage, which may weigh fifty pounds, holds no more dry matter than a cubic foot of overripe silage which weighs only about twenty-five pounds. Since this condition exists, measuring silage may get as close to the actual food value per cubic foot as weighing does per ton, if it is possible to get a reliable standard for measuring it.

An inspection of the weights of silage put into the various silos on the University Farm the last few years discloses a great variation in the tonnage which it is possible to put into a silo when the filling is carried on under different conditions. Tho these weights may vary a great deal from the theoretical capacity, the average of all the silos approaches it very closely.

CONDITION OF SILAGE

In 1911 the silage was put into two silos in a very green state, but at a fairly slow rate of filling, and 314 tons were placed in the silos. In 1914 the filling was carried on at about the same rate, but only 252 tons could be placed in the silos. This difference of 62 tons, which was 20 per cent, was due to the silage being so much riper in 1914 than in 1911.

RATE OF FILLING

In 1914 plenty of teams were available, and some of the silos were filled with a rush. That year two of them held only 209 tons, while the year previous, with the silage in approximately the same condition but filled slowly, they contained 252 tons, making a difference of 43 tons, or 17 per cent.

EFFECT OF SETTLING ON MEASURING SILAGE

Silage settles a great deal, but this settling nearly all takes place during the first two weeks after filling. Should the silo be filled and measured by the customary method for tons capacity within the same day, it would appear to contain at least 25 per cent more silage than if it were not measured for two weeks after being filled. Yet, practically the same amount of silage is in the silo. This is because the silage has settled so much during the two weeks.

The rule which at present is in vogue for determining the weight of silage in silos has been made up on the assumption that the depth is determined after two days of settling. A new one is proposed in this bulletin which will apply as accurately, if the depth of the silage is determined the day that filling ceases.

Altho it is known that measuring silage by the cubic foot and computing the weight is very unreliable, there are times when no other method is available, and then measuring is recommended.

WEIGHT OF SILAGE PER CUBIC FOOT

In 1889 King, of the Wisconsin Experiment Station, furnished a table giving the weight of silage per cubic foot at various depths. This has been quite universally adopted. His table gave the weight per cubic foot after the silage had settled for forty-eight hours. Both silo owners and manufacturers have used these weights, but in a majority of cases they have overlooked the fact that the silage must settle two days after filling before measuring their silage, and hence they have overrated their silos.

A NEW TABLE OF WEIGHTS

The Department of Agricultural Engineering proposes a new table of weights which assumes that the silage is in a normal condition when put into the silo; that the silo is filled without delay, allowed to settle from twelve to twenty-four hours, and then refilled; and that while filling, two men are kept in the silo tramping. The depth of silage should be determined at the close of the second filling.

This new table is made up on the assumption that King's is correct but cannot be conveniently used. It is a ratio of King's table, but the curve is smoother and longer and is verified by the weights of silage obtained at Nebraska. If it is assumed that silage settles 10 per cent after filling ceases, the Nebraska and King methods of computing capacities correspond very closely.

It will be noticed in comparing King's table of weights with the Nebraska table that the latter is from $11\frac{1}{2}$ to 13 per cent lighter than the former. The amount of silage which has been weighed into four different silos for the last six years indicates that the Nebraska table of weights is very nearly correct, but if anything, a fraction of a per cent too heavy.

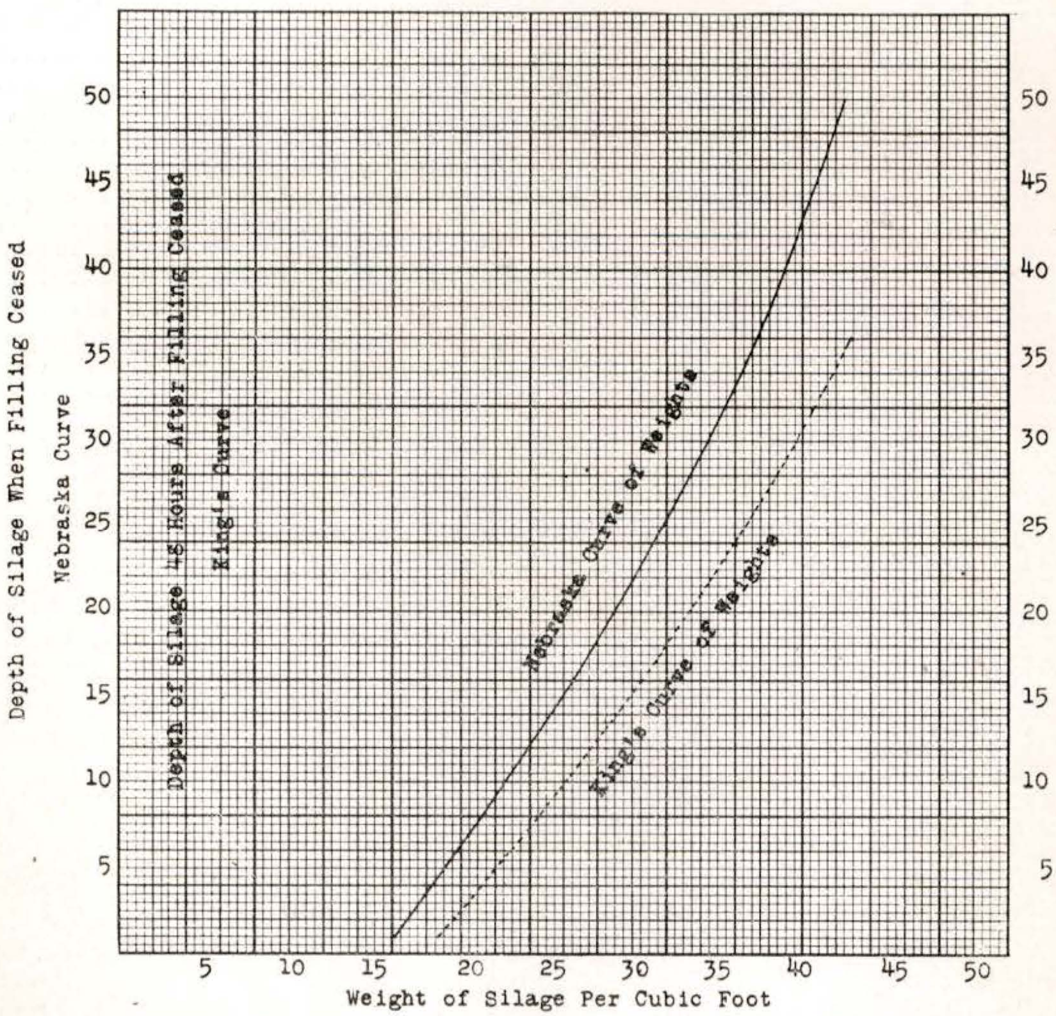

Diagram 1—Illustrating the Nebraska and King tables of weights

TABLE 1—*Weight of silage per cubic foot*

Depth of silage in feet	Weight per cu. ft.		Depth of silage in feet	Weight per cu. ft.	
	Nebraska	King		Nebraska	King
1	16.13	18.7	26	32.38	37.2
2	16.89	19.6	27	32.91	37.8
3	17.64	20.6	28	33.43	38.4
4	18.38	21.2	29	33.94	39.0
5	19.12	22.1	30	34.44	39.6
6	19.83	22.9	31	34.93	40.1
7	20.54	23.8	32	35.41	40.7
8	21.24	24.5	33	35.88	41.2
9	21.93	25.3	34	36.34	41.8
10	22.61	26.1	35	36.79	42.3
11	23.28	26.8	36	37.23	42.8
12	23.94	27.6	37	37.65	43.5
13	24.59	28.3	38	38.07	....
14	25.24	29.1	39	38.48	....
15	25.88	29.8	40	38.88	....
16	26.52	30.5	41	39.27	....
17	27.15	31.2	42	39.65	....
18	27.77	31.9	43	40.02	....
19	28.38	32.6	44	40.39	....
20	28.99	33.3	45	40.75	....
21	29.58	33.9	46	41.11	....
22	30.16	34.6	47	41.46	....
23	30.73	35.3	48	41.81	....
24	31.29	35.9	49	42.16	....
25	31.84	36.5	50	42.50	....

METHODS OF DETERMINING THE CAPACITIES OF SILOS

To determine the capacity of a silo, compute the inside volume, multiply this by the weight per cubic foot for that depth (obtained from table 1, or diagram 1), and divide by 2000. To do this, obtain the average inside diameter, if the silo is of the circular type. Then take one-half of this and multiply it by itself, then by 3.1416, then by the depth of the silo, then by the weight per cubic foot at this depth (obtained from the Nebraska table), and divide the whole by 2000. The answer is tons of silage. The tonnage in a silo 10 feet in diameter and 24 feet deep would be determined as follows: One-half of 10 is 5; then $5 \times 5 \times 3.1416 \times 24 \times 31.29 = 58{,}980$; $58{,}980 \div 2000 = 29.5$ tons. If King's weights per cubic foot are used, about 10 per cent should be added to the height of the silo to permit settling.

If a silo is square, rectangular, hexagonal, octagonal, or oval, the cross-sectional area must be obtained. This multiplied by the depth gives the volume, which, when multiplied by the weight per cubic foot for that depth and divided by 2000, gives the tonnage.

When the silo has integral dimensions, its capacity can be determined from table 2 by reading directly. Should it be 12 feet in diameter and 18 feet deep and filled full, it would have a capacity of 28.28 tons. (Follow out the 18 feet in depth line, table 2, until the 12 feet in diameter column is reached. The figures at this point are the tons capacity.)

TO DETERMINE THE TONS OF SILAGE IN SILOS

The tons of silage in a silo can be obtained in the same manner by using the depth of silage when filling ceased instead of the depth of the silo.

TABLE 2—*Relative capacities of silos and estimated tonnage of silage by volume*

Depth of silage in feet when filling ceased	Diameter of silo in feet									
	4	5	6	7	8	9	10	11	12	13
1	.10	.17	.23	.31	.40	.50	.63	.77	.95	1.07
2	.21	.33	.48	.65	.85	1.05	1.33	1.60	1.91	2.24
3	.33	.52	.75	1.04	1.33	1.64	2.07	2.52	2.99	3.51
4	.46	.73	1.04	1.43	1.85	2.29	2.88	3.49	4.16	4.88
5	.60	.95	1.35	1.84	2.40	2.98	3.75	4.54	5.40	6.33
6	.75	1.18	1.68	2.29	2.99	3.73	4.68	5.65	6.71	7.89
7	.90	1.42	2.03	2.76	3.61	4.46	5.64	6.84	8.12	9.54
8	1.07	1.68	2.40	3.27	4.27	5.29	6.68	8.03	9.60	11.27
9	1.24	1.95	2.79	3.79	4.95	6.15	7.75	9.38	11.16	13.09
10	1.42	2.24	3.20	4.35	5.68	7.04	8.84	10.76	12.78	15.44
11	1.61	2.53	3.62	4.92	6.43	7.97	10.08	12.16	14.48	16.98
12	1.80	2.84	4.06	5.53	7.22	8.93	11.30	13.64	16.25	19.05
13	2.01	3.15	4.51	6.14	8.04	9.94	12.53	15.18	18.07	21.20
14	2.22	3.49	5.00	6.80	8.88	11.00	13.90	16.89	20.00	23.46
15	2.44	3.84	5.49	7.46	9.77	12.80	15.24	18.45	21.96	25.76
16	2.66	4.18	6.00	8.16	10.65	13.19	16.75	20.19	24.00	28.16
17	2.90	4.55	6.52	8.88	11.59	14.34	18.12	21.95	26.11	31.30
18	3.13	4.94	7.07	9.60	12.55	15.54	19.60	23.77	28.28	33.30
19	3.38	5.33	7.62	10.38	13.55	16.77	21.16	25.62	30.49	35.75
20	3.64	5.72	8.19	11.11	14.56	18.00	22.78	27.55	32.75	38.45
21			8.77	11.96	15.56	19.30	24.40	29.52	35.14	41.23
22			9.36	12.75	16.66	20.30	25.96	31.54	37.54	44.05
23					17.77	21.92	27.14	33.61	40.00	46.95
24					18.88	23.35	29.50	35.67	42.45	49.85
25							31.30	37.85	45.20	52.83
26							33.08	40.00	47.66	55.45
27							34.92	42.21	50.28	59.00
28							36.78	44.50	53.00	62.13
29							38.67	46.80	55.75	65.31
30							40.60	49.16	58.50	68.60
31									61.27	71.90
32									64.12	75.20
33									67.00	78.50
34									69.82	82.10
35										
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TABLE 2 (cont'd)—*Relative capacities of silos and estimated tonnage of silage by volume*

Depth of silage in feet when filling ceased	Diameter of silo in feet								
	14	15	16	17	18	19	20	22	24
1	1.24	1.42	1.62	1.83	2.06	2.30	2.53	3.13	3.65
2	2.60	2.98	3.40	3.88	4.31	4.82	5.31	6.42	7.64
3	4.15	4.67	5.32	6.01	6.74	7.55	8.29	10.05	11.99
4	5.66	6.50	7.39	8.35	9.37	10.49	11.55	13.97	16.63
5	7.35	8.44	9.65	10.85	12.18	13.64	15.02	18.17	21.62
6	9.15	10.52	11.96	13.52	15.16	16.97	18.69	22.61	26.92
7	11.07	12.70	14.45	16.32	18.32	20.53	22.58	27.32	32.57
8	13.06	15.00	17.08	19.30	21.64	24.26	26.71	32.30	38.44
9	15.17	17.43	19.84	22.42	25.14	28.18	31.02	37.55	44.60
10	17.40	19.96	22.72	25.69	28.78	32.28	35.54	42.97	51.14
11	19.70	22.62	25.72	29.08	32.60	36.58	40.26	48.70	57.94
12	22.10	25.36	28.89	32.64	36.57	41.05	45.15	54.61	65.04
13	24.60	28.24	32.22	36.32	40.67	45.65	50.23	60.74	72.33
14	27.20	31.22	35.54	40.18	44.97	50.47	55.53	67.18	79.97
15	29.90	34.53	39.08	44.10	49.40	55.46	61.00	73.80	87.88
16	32.68	37.50	42.67	48.40	54.00	60.60	66.66	80.63	96.00
17	35.50	40.68	46.39	52.45	58.75	65.92	72.52	87.72	104.30
18	38.45	44.19	50.27	56.75	63.61	71.35	78.51	95.00	113.00
19	41.50	47.68	54.05	61.25	68.64	77.05	84.77	102.60	122.00
20	44.60	51.23	58.28	65.83	73.80	82.80	91.10	110.15	131.20
21	47.80	54.90	62.48	70.54	79.13	88.75	97.46	118.00	140.60
22	51.10	58.80	66.70	75.32	84.48	94.72	104.20	126.10	150.09
23	54.40	62.50	71.80	80.30	90.00	100.90	111.10	134.35	159.80
24	57.80	66.30	75.48	85.27	95.53	107.20	117.95	142.65	169.80
25	61.30	70.38	80.00	90.36	101.25	113.60	125.10	151.20	180.00
26	64.80	74.40	84.64	95.54	107.22	120.20	132.30	159.95	190.40
27	68.40	78.62	89.30	100.85	113.20	126.80	139.60	168.80	200.90
28	72.10	82.80	94.10	106.25	119.25	133.60	147.10	177.80	211.80
29	75.80	87.10	98.90	111.75	125.40	140.50	154.60	187.00	222.70
30	79.50	91.30	103.80	117.30	131.60	147.50	162.30	196.30	233.80
31	83.37	95.75	108.80	122.90	137.90	154.60	170.10	205.75	245.00
32	87.20	100.20	113.80	128.60	144.35	161.70	178.00	215.20	256.30
33	91.10	104.60	118.90	134.40	150.80	168.95	186.00	225.00	268.00
34	95.10	109.20	124.20	140.25	157.35	176.40	194.10	234.80	279.50
35	99.10	113.80	129.30	146.10	163.90	183.80	202.20	244.60	291.20
36	103.20	118.50	134.70	152.15	170.70	191.30	210.60	254.75	303.20
37	107.20	123.10	139.90	158.15	177.40	198.80	218.80	264.80	315.20
38	111.30	127.80	145.30	164.20	184.20	206.40	227.20	275.00	327.20
39	115.50	132.60	150.80	170.30	191.20	214.15	235.75	285.40	339.50
40	119.60	137.40	156.20	176.40	198.10	221.95	244.30	295.60	351.70
41	123.80	142.20	161.70	182.70	205.10	229.85	252.9	305.80	364.00
42	128.20	147.20	167.40	189.00	212.05	237.80	261.60	316.30	376.60
43	......	152.00	172.90	195.30	219.20	245.65	270.20	326.85	389.20
44	......	......	178.60	201.80	226.30	253.70	279.10	337.60	402.00
45	......	......	184.20	208.20	233.60	261.80	288.00	348.40	414.80
46	......	......	190.00	214.70	240.85	270.00	297.10	359.40	427.80
47	......	......	195.80	221.30	248.20	278.20	306.20	370.40	440.75
48	......	......	201.80	227.90	255.65	286.50	315.40	381.40	453.85
49	......	......	207.70	234.50	263.20	294.90	324.60	392.50	467.20
50	......	......	213.60	241.20	270.75	303.40	333.85	403.70	480.60

Should the silage have been partially fed out and it be desired to know the remaining amount, compute the tonnage (as above) for the silo when filling ceases. Then obtain the distance between the present level and the level when filling ceased, and compute the tonnage for this space. The difference between these two tonnages is a close approximation to the tons remaining in the silo.

The weight of silage per cubic foot is not the same for each foot in depth, but the deeper the silo the heavier each cubic foot of silage. As the silage becomes deeper the percentage of increase in weight becomes less. The capacity of a silo not only varies with the depth, as shown by the weights varying with the depth, but it also varies with the square of the diameter,—that is, a silo 8 feet in diameter will hold four times as much as one 4 feet in diameter.

RELATIVE DIMENSIONS OF SILOS

If two silos have the same capacity but vary in height and diameter, the taller and narrower silo will be somewhat more expensive, but it will have much less spoiled silage on top each year, which will compensate for the difference in original cost.

SIZE OF SILO

The silage must be fed off at the rate of about $1\frac{1}{2}$ inches per day during the warm winter days and twice as fast in the summer in order to prevent spoiling. The diameter of the silo needed must be determined by the number and kind of stock being fed from it in summer, if summer and winter feeding is carried on; or by the number and kind being fed in the winter, if winter feeding only is practiced.

The height of the silo should be determined by the length of feeding period.

The first step in deciding the size of the silo is to determine the kind of live stock and the number to be fed. The number of days the stock is to be fed determines the capacity required, and from this we get the diameter and height of the silo. If it is anticipated that at any time of the year more stock than the minimum number are to be fed, the capacity of the silo should be increased by increasing the height rather than by increasing the diameter.

Where a large number of animals are to be fed from a silo it is always better to build two silos of a smaller diameter than one of an extremely large diameter. This is especially true of stave silos. The shell of a large stave silo is no thicker than the shell of a small silo, but its sides are more nearly flat. Hence, it will not resist the wind pressure nearly so well as a small silo.

AN ANALYSIS OF THE WEIGHTS OF SILAGE PUT INTO SILOS ON THE UNIVERSITY FARM

In 1910 it was decided to weigh the silage at the University Farm and, if possible, check King's tables of weights. The variation found in that year was so interesting that weighing the silage has continued each year since.

There were but three silos on the Farm in 1910. During the summer of 1911, one of these was blown down and a larger one erected in its place. A new one was built at another barn, making four. Weights were not obtained in 1912, and in 1913 conditions for filling silos were so unfavorable that the weights from only two silos were saved. In 1914 another silo was added and weights obtained from all five. The weighing carried on in 1914 was repeated in 1915. In 1916 the silos were not all completely emptied, and the weights from only three could be used.

Data gathered during these years lead to the belief that King's table of weights will not prove correct for silos of small diameters. A silo twelve feet in diameter has been added to the battery of silos at the University Farm, and during the three years that weights have been kept on it, the average weight per cubic foot has been much lower than that shown by the Nebraska or King tables and curves.

Results of the observations made during these years are illustrated in the accompanying diagrams.

The department of Animal Husbandry furnishes the following table as an approximate guide for the amount of silage to be fed daily under average conditions to the various ages and kinds of stock.

TABLE 3—*Approximate daily ration of silage*

Kind of stock	Weight	Fed per day
Horses	*Pounds*	*Pounds*
Colts	500	5
Stock horses	1,200	12
Work horses	1,300	10
Cattle		
Calves	500	12
Stock cattle	1,000	20
Beef cows	1,300	30
Dairy cows	1,000	40
Fattening cattle	1,200	25
Sheep		
Stock sheep	....	3
Fattening sheep	....	3

Table 3 shows that if each dairy cow requires 40 pounds per day, 27 cows would require 1,080 pounds daily and for a 180-day feeding season they would require 194,400 pounds, which is practically 97 tons of good feed. Since there is always some spoiled silage the silo should hold at least 100 tons. If the feeding season is to be extended, the capacity of the silo must be increased.

In table 4 it is found that a silo should be about 14 feet in diameter to furnish the proper amount of feed for 27 cows. It will be seen from table 2 that a silo 14 feet in diameter and 36 feet deep will hold 103 tons.

TABLE 4—*Rate of feeding from silos of different diameters*

Diameter in feet	Approximate minimum pounds to be fed daily		[1]Approximate number of the different kinds of stock to keep the silage from spoiling in summer					
	Summer	Winter	Horses	500-lb. calves	Stock cattle	Beef cattle	Dairy cows	Sheep
10	525	263	48	44	26	21	13	175
12	755	378	69	63	38	30	19	252
14	1,030	515	94	86	52	41	26	344
16	1,340	670	122	112	67	54	34	446
18	1,700	850	155	142	85	68	42	567
20	2,100	1,050	191	175	105	84	53	700

[1]If the silo is to be used for winter feeding only, it will require only one-half as many of each kind of stock to keep the silage in good condition as where it is used for summer feeding.

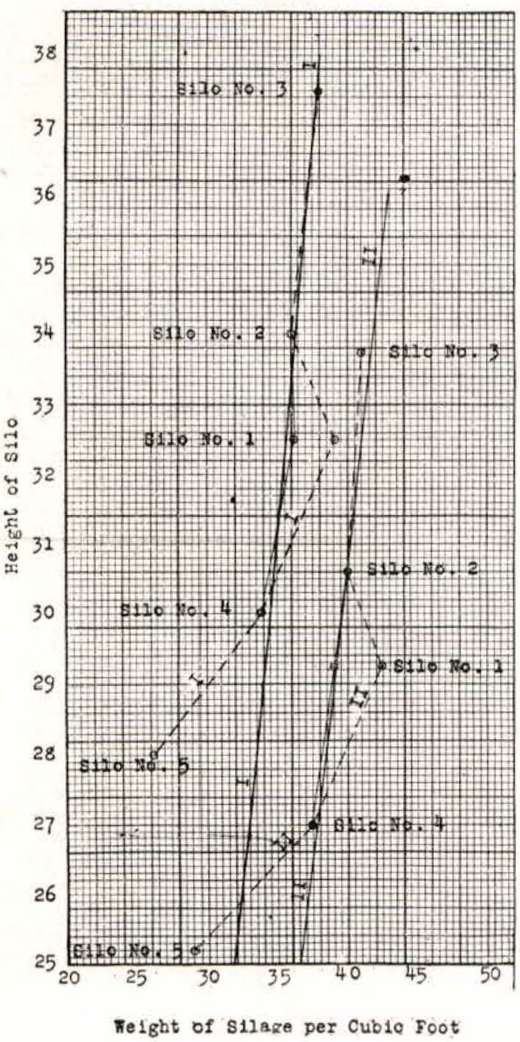

Diagram 2

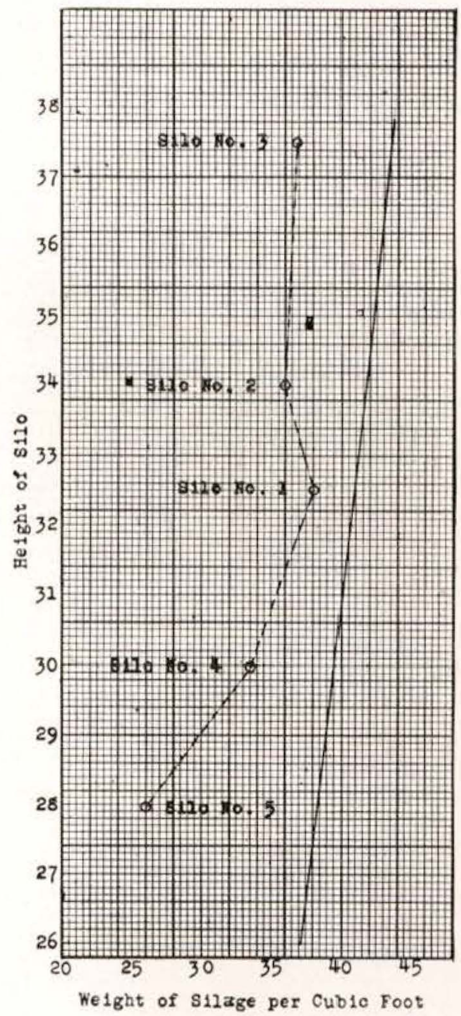

Diagram 3

Diagram 2—Illustrating how the weights of silage per cubic foot in the silos at Nebraska compare with the Nebraska curve of weights and with King's curve of weights when there is a ten per cent settlement. One year silo No. 1 was filled with very green silage, and when that year's weights are removed the dotted line assumes the course of the light, full line

Diagram 3—This diagram shows how far apart are King's ratings as commonly but erroneously used and the weights of silage as put into the silos at Nebraska Experiment Station

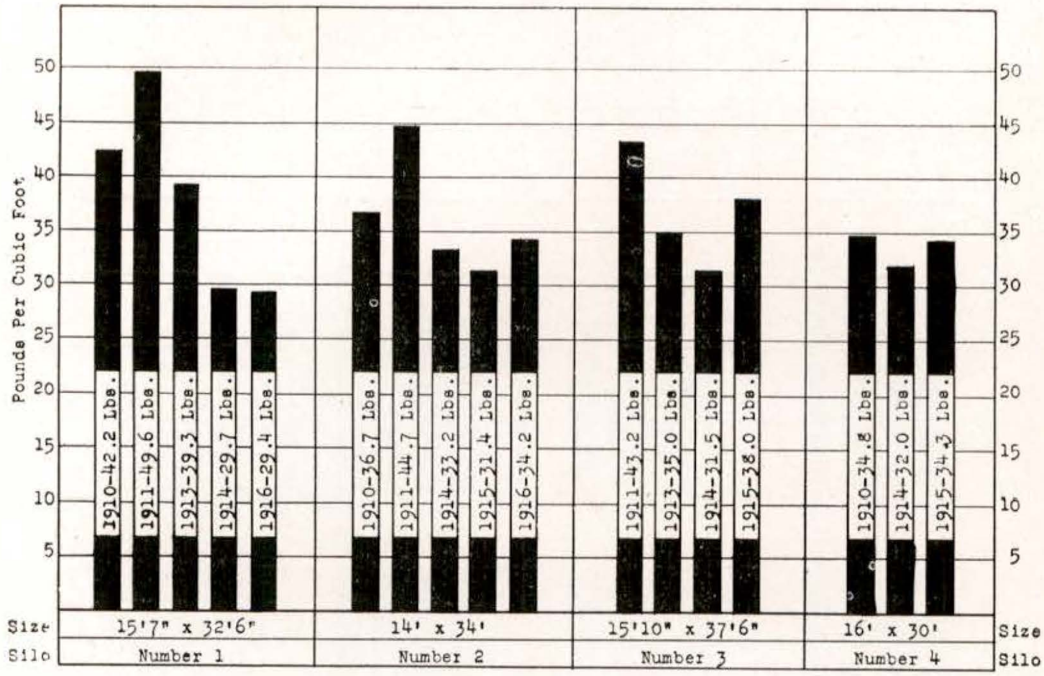

Diagram 4—Illustrating how much the weight per cubic foot of silage is affected by the conditions under which it is put into the silo.

Silo Number 1 was filled with green silage in 1911 and normal silage in 1914 and 1916. In 1913 it was filled slowly with normal silage, while in 1914 it was filled quickly with similar silage.

Silo Number 2 was filled with green silage in 1911 and a trifle too ripe silage in 1915.

Silo Number 3 was filled very quickly in 1914 but slowly in 1915.

Silo Number 4 has been filled under nearly the same conditions at all times.

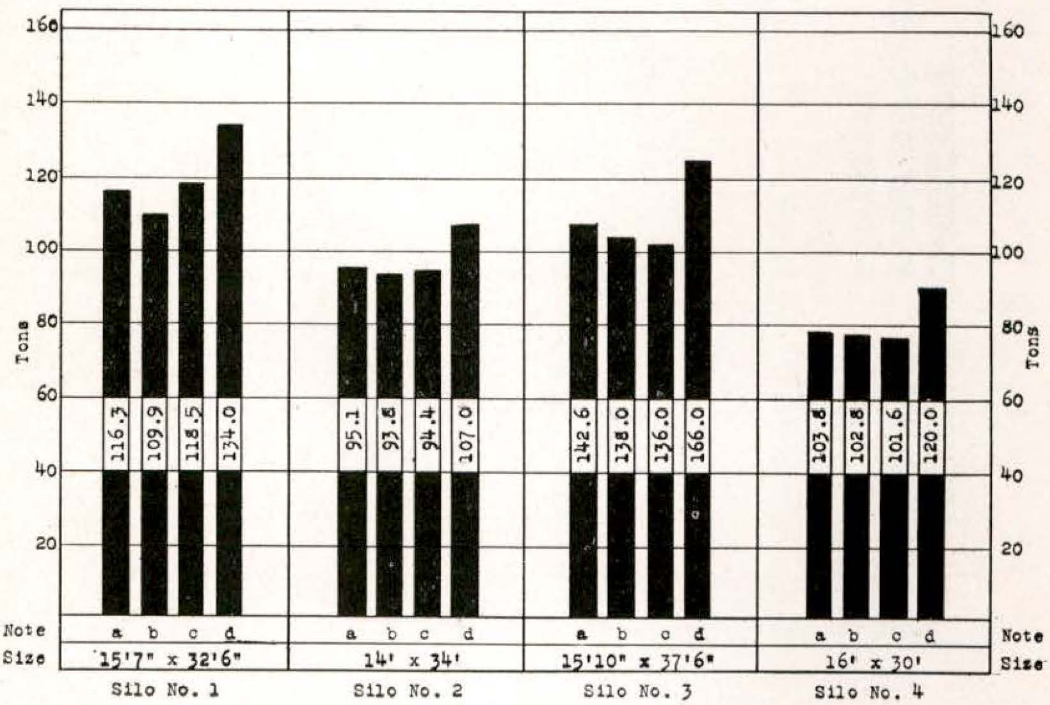

Diagram 5—Illustrating the capacities of four silos when determined by the Nebraska method (a a a a); by the King method with 10 per cent settle (b b b b), by weighing the contents of the silos, six-year period (c c c c); and by the King method as commonly used (d d d d).

TABLE 5—*Actual and theoretical capacities of silos (University Farm)*

Silo	Condition of silage	Rate of filling	Diameter of silo	Depth of silo	Tons put in	Weight per cubic foot	King's rating as commonly used	Computed capacity	
								Nebraska rating	King's rating with 10% settle
1........	Normal	Slow	15 ft. 7 in.	32.5 ft.	132.0	42.2	134	116.35	109.9
1........	Green	Slow	15 ft. 7 in.	32.5 ft.	155.0	49.6	134	116.35	109.9
1........	Normal	Slow	15 ft. 7 in.	32.5 ft.	123.0	39.4	134	116.35	109.9
1........	Normal	Fast	15 ft. 7 in.	32.5 ft.	92.7	29.7	134	116.35	109.9
1........	Normal	Slow	15 ft. 7 in.	32.5 ft.	92.0	29.4	134	116.35	109.9
	Five years' average..........			....	**118.9**	**38.0**	**134**	**116.35**	**109.9**
2........	Normal	Slow	14 ft.	34.0 ft.	96.0	36.7	107	95.10	93.8
2........	Green	Slow	14 ft.	34.0 ft.	117.0	44.7	107	95.10	93.8
2........	Normal	Fast	14 ft.	34.0 ft.	86.8	33.2	107	95.10	93.8
2........	Dry	Slow	14 ft.	34.0 ft.	82.3	31.4	107	95.10	93.8
2........	Normal	Slow	14 ft.	34.0 ft.	89.5	34.2	107	95.10	93.8
	Five years' average..........			....	**94.4**	**36.0**	**107**	**95.10**	**93.8**
3........	Green	Slow	15 ft. 10 in.	37.5 ft.	159.0	43.1	166	142.60	138.0
3........	Normal	Slow	15 ft. 10 in.	37.5 ft.	129.0	34.8	166	142.60	138.0
3........	Normal	Fast	15 ft. 10 in.	37.5 ft.	116.2	31.5	166	142.60	138.0
3........	Green	Slow	15 ft. 10 in.	37.5 ft.	139.8	37.9	166	142.60	138.0
	Four years' average........			....	**136.0**	**36.9**	**166**	**142.60**	**138.0**
4........	Ripe	Slow	16 ft.	30.0 ft.	105.0	34.8	119	103.80	102.8
4........	Normal	Fast	16 ft.	30.0 ft.	96.4	32.0	119	103.80	102.8
4........	Normal	Slow	16 ft.	30.0 ft.	103.3	34.3	119	103.80	102.8
	Three years' average........			....	**101.6**	**33.7**	**119**	**103.80**	**102.8**
5........	Normal	Fast	12 ft.	28.0 ft.	45.6	28.8	61	53.00	52.1
5........	Dry	Fast	12 ft.	28.0 ft.	33.4	21.1	61	53.00	52.1
5........	Normal	Fast	12 ft.	28.0 ft.	45.0	28.4	61	53.00	52.1
	Three years' average........			....	**41.3**	**26.1**	**61**	**53.00**	**52.1**

APPENDIX

Tons silage per acre (University Farm)

Field	Year	Number acres	Total tons silage	Tons per acre
Cook	1914	5.63	56.32	10.012
Lot 4	1914	8.45	72.91	8.628
Vine St	1914	26.75	253.53	9.478
Hammond	1914	3.25	22.01	6.770
Pirner	1914	3.82	31.62	8.266
Pirner	1915	32.75	345.01	10.534
Lot 4	1915	8.45	63.56	7.522
Hammond	1915	2.90	32.19	11.100
Cook	1915	1.13	16.29	11.480
Average of all fields				9.593